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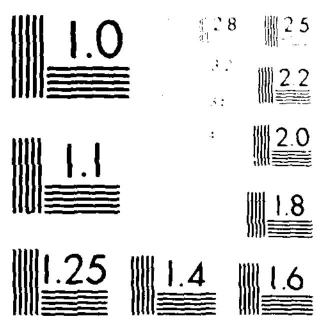

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A MODIFIED JONSWAP SPECTRUM DEPENDENT ONLY ON WAVE HEIGHT AND PERIOD

A MODIFIED JONSWAP SPECTRUM DEPENDENT ONLY ON WAVE HEIGHT AND PERIOD

by

Wah T. Lee

and

Susan L. Bales

SHIP PERFORMANCE DEPARTMENT

May 1980

DTNSRDC/SPD-0918-01

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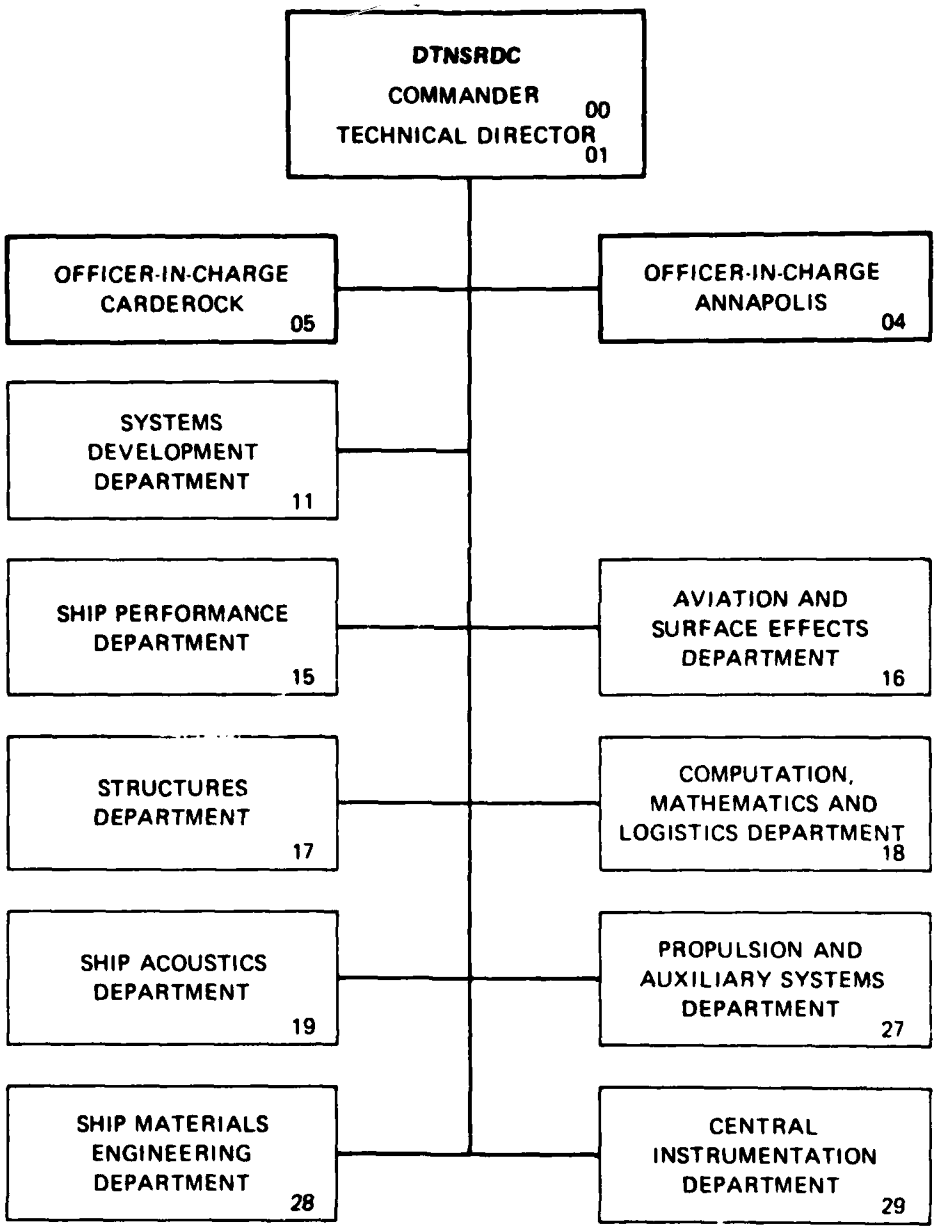

"Development of Consistent Natural Environment Parameter Sets for Combantant Capability Assessment (CCA)," by Lee and Bales, Report DTNSRDC/SPD-0795-02 (Mar 1980)

Errata

1. p. 7 - fourth line in second paragraph should read "L_i and λ_i are latitude and longitude in degrees, respectively"

DAVID W. TAYLOR NAVAL SHIP RESEARCH
AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20084

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20084

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For simplicity as well as consistency with the current state-of-the-art in seakeeping performance assessment, a wave spectral formulation for fetch-limited ocean areas which is dependent only on the significant wave height and modal wave period is desirable. A modified version of the JONSWAP spectrum is therefore derived, but as is the case with the usual fetch-dependent JONSWAP spectrum, it contains too much energy for fetches above

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NOTATION

f	Wave frequency, cycles · sec^{-1} or Hertz
f_o	Frequency corresponding to the peak of the wave spectrum, cycles · sec^{-1}
g	Acceleration due to gravity, 9.8087 m · sec^{-2}
m_o	Spectral moment of order zero
$S_\zeta(f), S_\zeta(\omega)$	Long-crested wave spectral density ordinates
U	Wind speed, at 10 m above ocean surface
X	Fetch
$(\tilde{\zeta}_w)_{1/3}$	Significant wave height, average of one-third highest double amplitudes
T_o	Modal wave period, period corresponding to the frequency of the peak of wave spectrum
α	Phillip's constant
β	A constant dependent on the significant wave height and modal wave period
γ	Ratio of the maximal spectral energy to the maximum of the corresponding Pierson-Moskowitz spectrum
σ_a, σ_b	Left, right side widths of spectral peak of JONSWAP spectra
ω	Wave frequency, radians · sec^{-1}

ABSTRACT

For simplicity as well as consistency with the current state-of-the-art in seakeeping performance assessment, a wave spectral formulation for fetch-limited ocean areas which is dependent only on the significant wave height and modal wave period is desirable. A modified version of the JONSWAP spectrum is therefore derived, but as is the case with the usual fetch-dependent JONSWAP spectrum, it contains too much energy for fetches above about 40 nautical miles. This inconsistency is probably due to certain parameter relationships which are all based on least squares fits. Therefore, a new parameter, β, is developed to replace the usual α parameter, correcting for the parameter's nonuniversality.

ADMINISTRATIVE INFORMATION

This report was prepared under the sponsorship of the Conventional Ship Seakeeping Research and Development Program, funded under Project Number 62543N and Block Number SF 43 421 202 and the Ship Performance and Hydromechanics Program, funded under Project Number 62543N and Block Number SF 43 421 001. It is identified by Work Unit Number 1504-100 and 1500-104, respectively, at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC).

INTRODUCTION

The primary goals of the Joint North Sea Wave Project (JONSWAP), which originated in 1967, were to measure the growth of waves under limited fetch conditions and to analyze attenuation of waves propagating into shallow water, see References 1 and 2.* The fetch dependence of the measured one-dimensional frequency spectra was investigated by parameterizing them with an analytic function derived by least squares fit techniques. The resulting function, currently the most widely used spectrum for representing fetch-limited seas, is known as the JONSWAP spectral density equation and is given by

$$S_\zeta(f) = \alpha\, g^2\, (2\pi)^{-4}\, f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_o}\right)^{-4}\right] \gamma^{\exp\left[-\frac{(f-f_o)^2}{2\sigma^2 f_o^2}\right]} \quad m^2\text{-sec} \qquad (1)$$

*A complete listing of references is given on page 9.

which reflects the five parameters of f_o α, γ, σ_a and σ_b shown in Figure 1. f is the wave frequency in cycles · sec^{-1}, f_o is the frequency at the spectral peak, and g is the acceleration due to gravity. In this report, a "mean" JONSWAP spectrum has been used, so that γ is 3.3, σ_a is 0.07 and σ_b is 0.09. The two parameters, α and f_o, are dependent on the wind speed and fetch such that

$$\alpha = 0.076\ \tilde{X}^{-0.22} \tag{2}$$

and

$$f_o = \frac{\tilde{f}_o g}{U} \tag{3}$$

where

$$\tilde{X} = \frac{gX}{U^2} \tag{4}$$

and

$$\tilde{f}_o = 3.5\ \tilde{X}^{-0.33},\ \tilde{X} < 10^4 \tag{5}$$

X is the fetch in nautical miles. The wind speed U is taken to be at an elevation of 10 m above the surface and is in units of knots.

The JONSWAP spectral form represents a generalization of the Pierson-Moskowitz form by inclusion of fetch as an additional parameter to wind speed. If α is 0.0081 and γ is 1 in equation (1), the JONSWAP spectral form is identical to the Pierson-Moskowitz form. In general, the JONSWAP spectrum contains more peak energy than the corresponding Pierson-Moskowitz spectrum for the same values of α and f_o, see Figure 1.

MODIFICATION OF THE JONSWAP SPECTRUM

In previously completed ship seakeeping analyses, e.g., see Reference 3, in which the ship's operations in fetch-limited waters has to be assessed, it has been customary to apply the JONSWAP spectrum, defined by wind speed and fetch as given in equation (1). However, for simplicity as well as consistency with the current state-of-the-art in seakeeping performance assessment, a JONSWAP expression which is dependent only on the two parameters, significant wave height and modal wave period, is also desirable. In order to achieve this, the following steps have been carried out. Eliminating the dimensionless frequency $\tilde{f}_o$ from equations (3) and (5),

$$U = \frac{3.5\ \tilde{X}^{-0.33} g}{f_o} \tag{6}$$

where

$$f_o = \frac{1}{T_o} \tag{7}$$

or

$$U = 3.5\ \tilde{X}^{-0.33} g\ T_o \tag{8}$$

The fetch dependence of the dimensionless total energy in the wave spectrum is given as

$$\tilde{m}_o = \frac{m_o g^2}{U^4} \tag{9}$$

Furthermore, another fetch empirical relationship is well represented by the following relation

$$\tilde{m}_o = 1.6\ (10^{-7})\tilde{X},\ \tilde{X} < 10^4 \tag{10}$$

where m_o is the spectral moment of order zero. Significant wave height $(\tilde{\zeta}_w)_{1/3}$ can be defined as

$$(\tilde{\zeta}_w)_{1/3} = 4\ \sqrt{m_o} \text{ or } m_o = \frac{(\tilde{\zeta}_w)_{1/3}^{\ 2}}{16} \tag{11}$$

and substituting into equation (9) gives

$$\tilde{m}_o = \frac{(\tilde{\zeta}_w)_{1/3}^{\ 2}\ g^2}{16\ U^4} \tag{12}$$

Combining equations (8) and (12),

$$\tilde{m}_o = \frac{(\tilde{\zeta}_w)_{1/3}^{\ 2}\ g^2}{16(3.5\ \tilde{X}^{-0.33} g\ T_o)^4} \tag{13}$$

Eliminating the term $\tilde{m}_o$ from equations (10) and (13) yields

$$1.6\ (10^{-7})\tilde{X} = \frac{(\tilde{\zeta}_w)_{1/3}{}^2\ g^2}{16\ (3.5\ \tilde{X}^{-0.33} g\ T_o)^4} \tag{14}$$

or

$$\tilde{X}^{-0.32} = \frac{(\tilde{\zeta}_w)_{1/3}{}^2\ 2603.082}{g^2\ T_o{}^4} \tag{15}$$

This equation can also be written in the form

$$\tilde{X}^{-0.22} = \frac{222.92\ (\tilde{\zeta}_w)_{1/3}{}^{1.375}}{g^{1.375}\ T_o{}^{2.75}} \tag{16}$$

Substituting $\tilde{X}$ into equation (2)

$$\alpha = 0.076\left[\frac{222.92\ (\tilde{\zeta}_w)_{1/3}{}^{1.375}}{g^{1.375}\ T_o{}^{2.75}}\right] \tag{17}$$

or

$$\alpha = \frac{16.942\ (\tilde{\zeta}_w)_{1/3}{}^{1.375}}{g^{1.375}\ T_o{}^{2.75}} \tag{18}$$

The JONSWAP equation can now be rewritten in terms of $(\tilde{\zeta}_w)_{1/3}$ and T_o as

$$S_\zeta(f) = \frac{16.942\ (\tilde{\zeta}_w)_{1/3}{}^{1.375}}{g^{1.375}\ T_o{}^{2.75}}\ g^2\ (2\pi)^{-4}\ f^{-5}\ \exp\left[-1.25(fT_o)^{-4}\right]\gamma^{\exp-\frac{1}{2\sigma^2}\left[fT_o-1\right]^2} \quad m^2\text{-sec} \tag{19}$$

Equation (19) can be further rewritten to be more compatible with the usual Bretschneider spectral density formulation as well as most ship response calculation procedures by converting f to ω, the circular frequency in radians $\cdot$ sec^{-1}, and taking $\gamma = 3.3$,

$$S_\zeta(\omega) = \frac{16.942\ (\tilde{\zeta}_w)_{1/3}^{\ 1.375}}{g^{1.375}\ T_o^{\ 2.75}}\ g^2\ \omega^{-5}\ \exp\left[-1.25\left(\frac{\omega T_o}{2\pi}\right)^{-4}\right]\ 3.3^{\exp-\frac{1}{2\sigma^2}\left[\frac{\omega T_o}{2\pi}-1\right]^2}$$

$$m^2\text{-sec} \qquad (20)$$

where

$$\sigma = 0.07 \text{ for } \frac{\omega}{2\pi} \leq \frac{1}{T_o} \qquad (21)$$

or

$$\sigma = 0.09 \text{ for } \frac{\omega}{2\pi} > \frac{1}{T_o} \qquad (22)$$

β PARAMETER

The modified JONSWAP spectrum given by equation (20) contains more energy than it is theoretically supposed to for the same values of significant wave height and modal wave period when these two parameters are used to define the spectrum.* Figure 2 provides an illustration of the difference in significant wave height at the same fetch for winds of 20 and 30 knots. The solid line represents the theoretical relationship between significant wave height and fetch for those wind speeds. The dashed line represents the values which are actually computed from the spectral area when the given fetch and wind speed are specified in the usual JONSWAP formulation given in equation (1). The difference between the solid and dashed lines represents a rather noticeable increase in significant wave height for fetches above 40 nautical miles. The difficulty arises due to the fact that the absolute value of α is not universal, as was first suggested by Phillips, and also as described by Ewing in Reference 4. While the $\tilde{f}$ and $\tilde{X}$ data are well defined in the linear regression fits, see equations (5) and (10), there is a large scatter for

*This inconsistency is also present when the usual JONSWAP formulation, given in equation (1), is applied and is particularly noticeable for fetches above about 40 nautical miles.

absolute values of $\tilde{X}$ larger than 10^4. Consequently, the basic form of equation (2), and hence equation (18), is not universal at relatively high waves and periods. To correct this anomaly, a new parameter, β, is developed to replace the α parameter given in the usual JONSWAP formulation. The technique developed to compute β is given in the Appendix. Figures 3 and 4 are the result and provide β for given values of significant wave height and modal wave period. The wave parameter ranges are deliberately broad in anticipation of any extreme occurrences such as those reported in the North Sea. The β parameter assures that the specified (input) significant wave height, see equation (18), corresponds to that which is calculated from the integration of the resulting spectral ordinates. The modified JONSWAP formulation given in equation (20) can now be rewritten as

$$S_\zeta(\omega) = \beta\, g^2\, \omega^{-5} \exp\left[-1.25\left(\frac{\omega T_o}{2\pi}\right)^{-4}\right] 3.3^{\exp-\frac{1}{2\sigma^2}\left[\frac{\omega T_o}{2\pi} - 1\right]^2} \quad m^2\text{-sec} \qquad (23)$$

where β is a constant dependent only on the significant wave height, $(\tilde{\zeta}_w)_{1/3}$, and the modal wave period, T_o.

APPLICATIONS OF THE MODIFIED JONSWAP SPECTRUM

Figures 5 and 6 provide sample JONSWAP (modified) spectra for significant wave heights of 2, 3, 5, and 7 meters and a range of modal wave periods. As is the case with the Bretschneider formulation, equation (23) can be applied without special regard to fetch or wind speed. The user, upon selecting the values for significant wave height and modal wave period (e.g., from historical wave statistics, climatology, etc.), determines β from Figures 3 or 4 and thence the spectrum can be developed. Figures 3 and 4 contain a limited but realistic range of modal wave periods for given significant wave heights for fetch limited geographies.

Table 1 provides comparisons of significant wave heights for different values of γ. By substituting a set of significant wave height values (e.g., from Table 1) in the abscissa scale of Figures 3 and 4, β values can be obtained for various values of γ. Since a range of fetch or wind speed values used to obtain β could be of interest in some seakeeping analyses (e.g., for specific ocean areas), Figures 7 and 8, developed from computer program JON1 as detailed in the Appendix, provide a comparison with corresponding height and period ranges.

As with the usual JONSWAP formulation, the modified expression given in equation (23) is for long-crested seas. The cosine squared spreading function can be used with the spectrum but insufficient data on the directionality of wave systems in fetch-limited waters is available to verify its applicability.

VALIDATION OF MODIFIED FORMULATION

The general shape of the modified JONSWAP spectra agree well with the shape of the measured spectra reported for Argus Island in Reference 5. Several such comparisons are given in Figure 9. Furthermore, a total of four spectra in the North Sea, hindcast by the U.S. Navy's Spectral Ocean Wave Model (SOWM), see Reference 6, were randomly selected for comparison with the modified JONSWAP formulation. The hindcasts were also compared with Bretschneider spectra defined using the hindcast significant wave height and modal period. Figure 10 shows these comparisons. In general, the modified JONSWAP spectra provide a much closer approximation to the hindcasts than do the Bretschneider spectra though secondary spectral peaks are, of course, not well approximated due to the unimodal restriction of the model. The modal wave period has been used as the defining parameter of the spectra in this comparison. However, since some hindcast spectra contained multiple peaks, average wave period (e.g., zero crossing period) may permit a better shape definition of the theoretical wave spectra.

CONCLUDING REMARKS

An expression of the mean JONSWAP spectrum dependent on the significant wave height and modal wave period is derived. However, as is the case with the usual fetch-dependent JONSWAP spectrum, it contains too much energy for fetches above about 40 nautical miles. The inconsistency arises due to the fact that the absolute value of α is not universal, while the $\tilde{f}$ and $\tilde{X}$ data are well-defined in the least squares fits (equations (5) and (10)). Further, there is a broad scatter for absolute values of $\tilde{X}$ larger than 10^4.

β is developed to replace the α parameter given in the usual mean JONSWAP formulation and to correct for the parameter's nonuniversality. Figures 3 and 4 permit the determination of β for given values of significant wave height and modal wave period. Hence, wave energy is conserved in the modified JONSWAP formulation.

Recent hindcast spectra from the North Sea, as well as actual wave measurements from fetch-limited areas, suggest that the modified JONSWAP spectrum may describe wave growth conditions more realistically than the Bretschneider spectrum in fetch-limited or shallow water conditions. In general, it is concluded that the modified JONSWAP spectrum provides a reasonable representation of wave conditions in fetch-limited or shallow water ocean areas.

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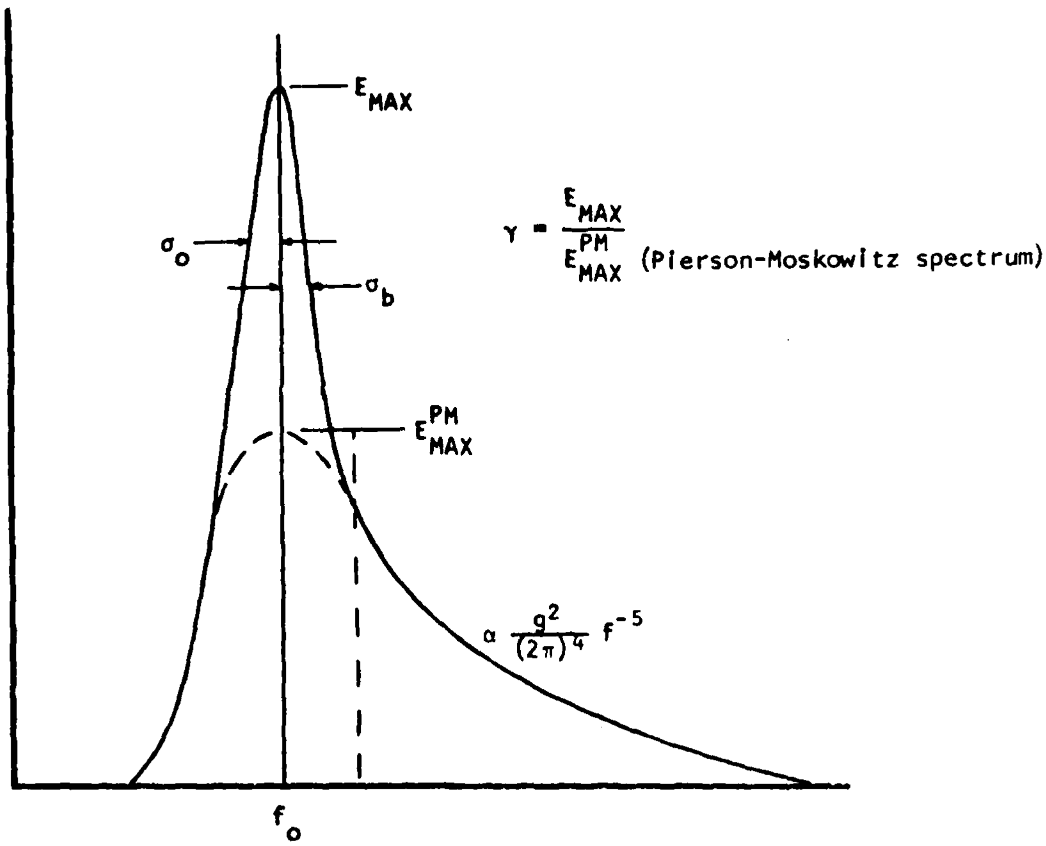

Figure 1 - Description of Five Defining Parameters of the JONSWAP Spectrum

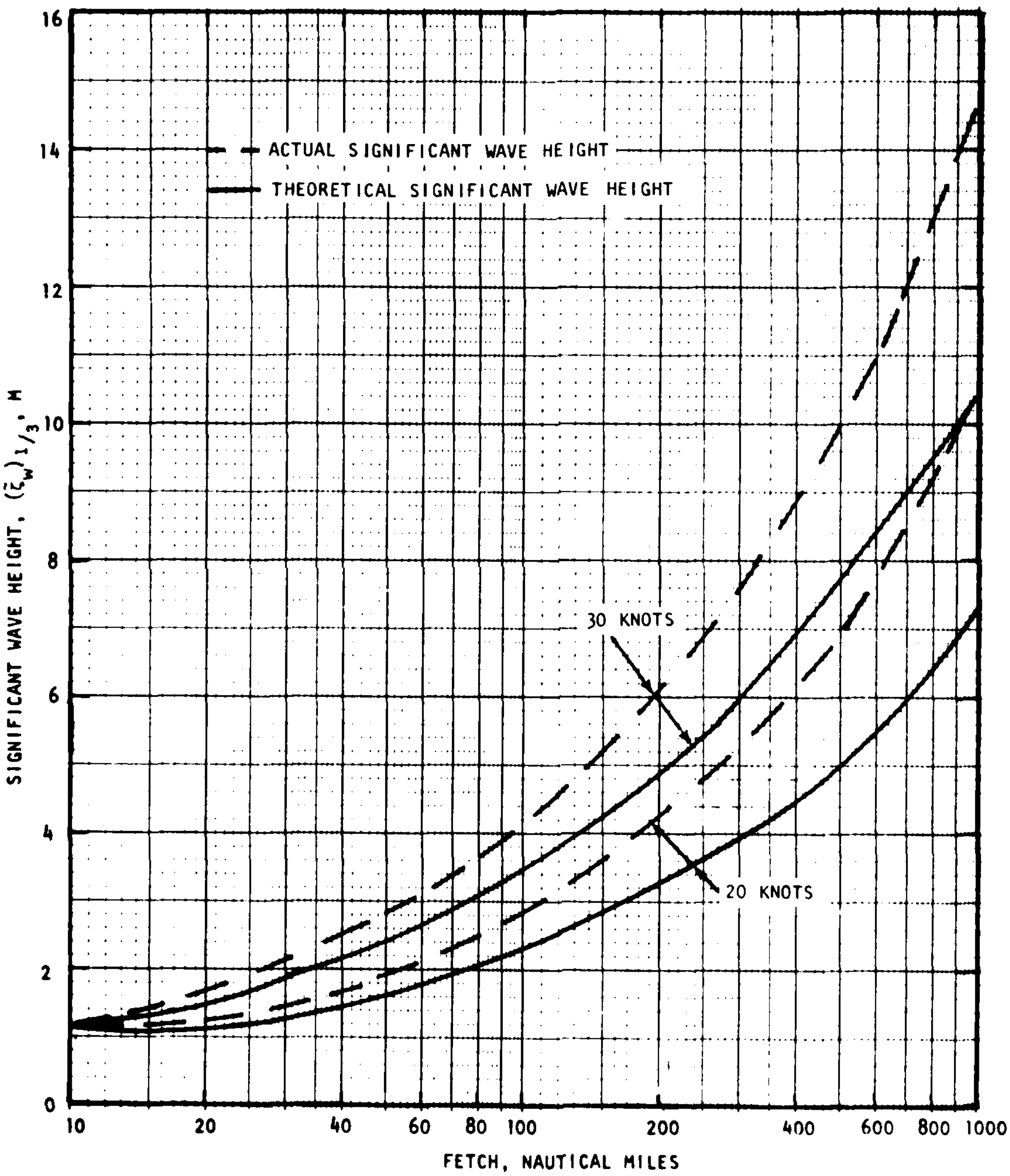

Figure 2 - Comparisons of JONSWAP Theoretical and Actual Significant Wave Height and Fetch Relationships

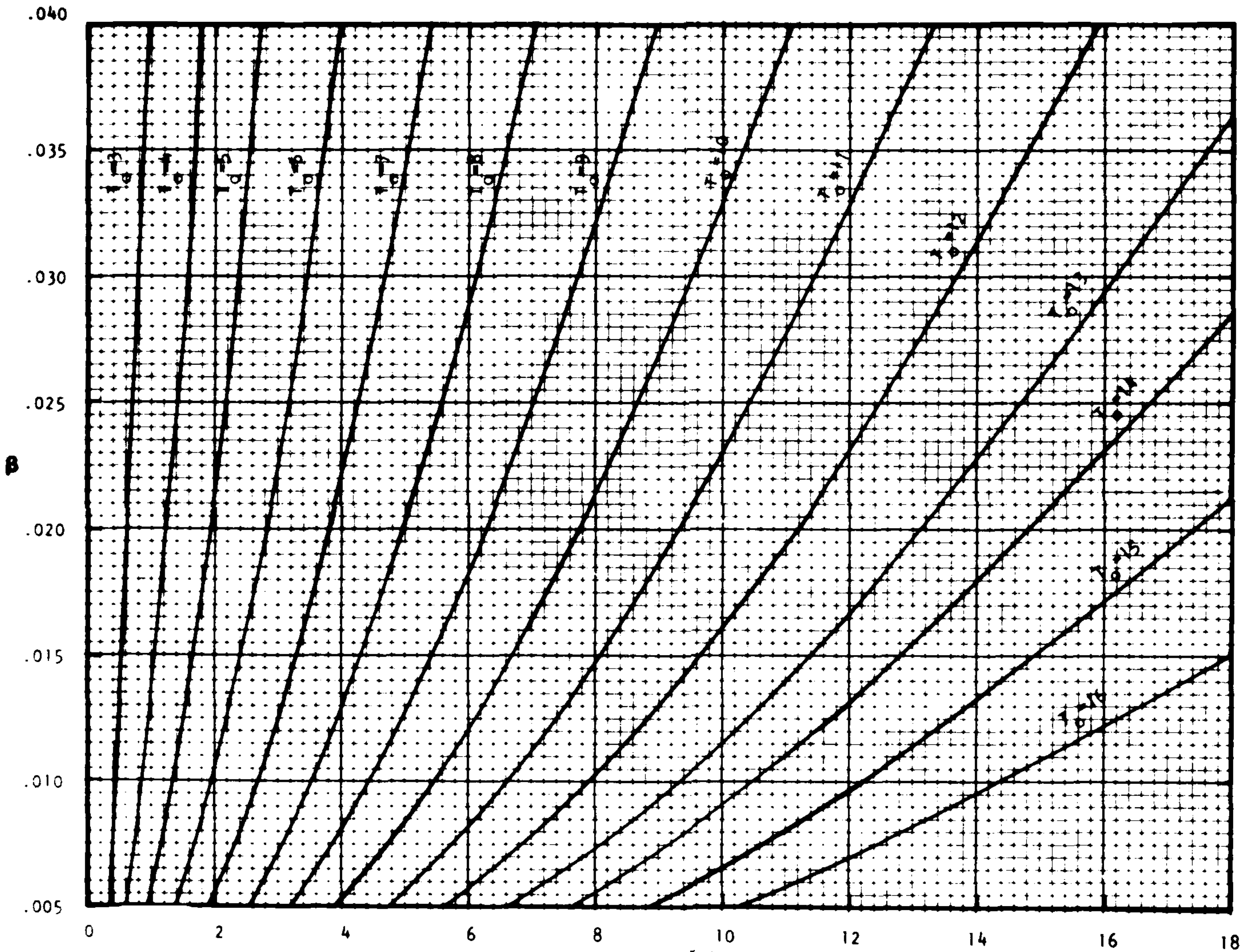

Figure 3 - Determination of β for Modified JONSWAP Spectrum

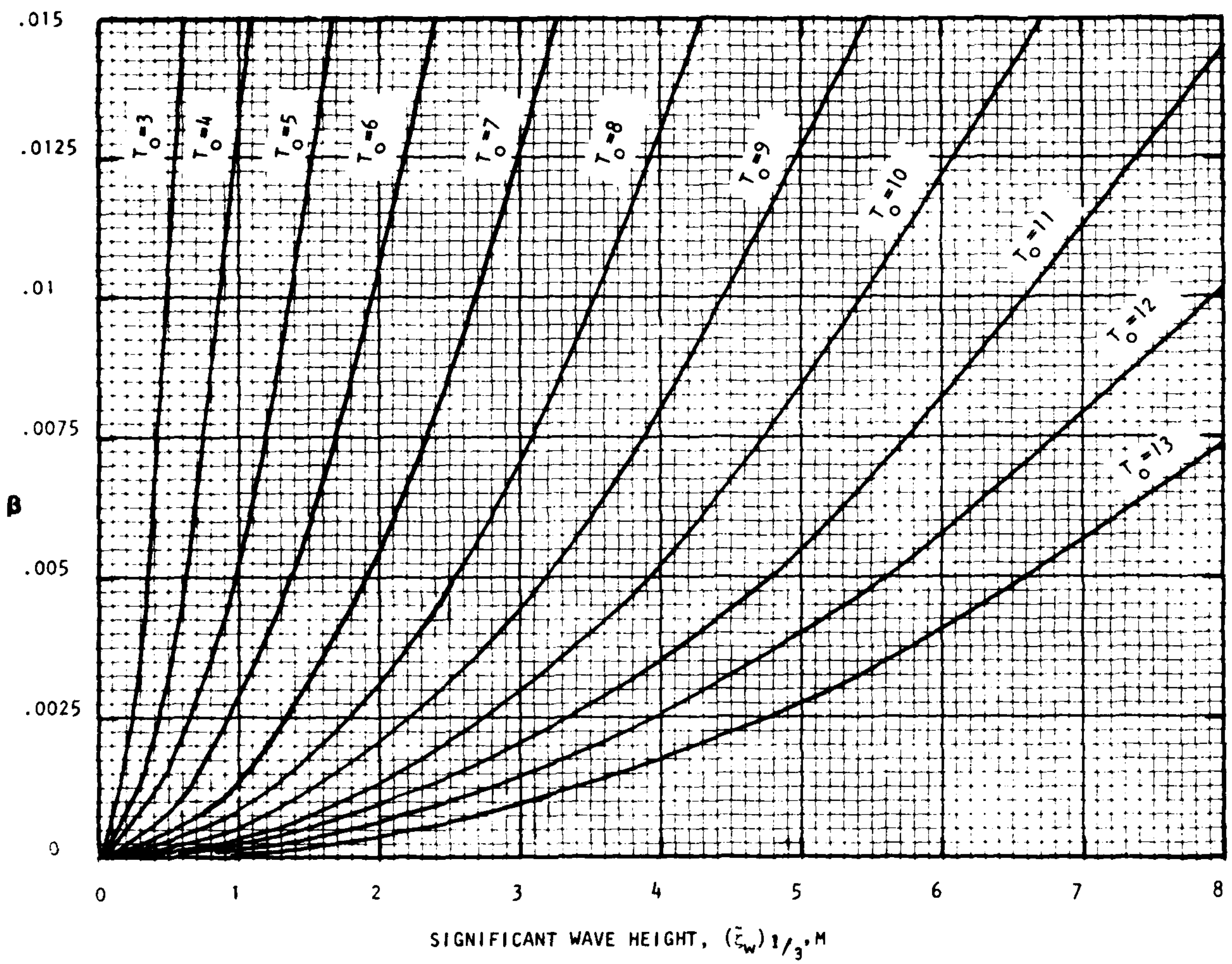

Figure 4 - Determination of Small β for Modified JONSWAP Spectrum

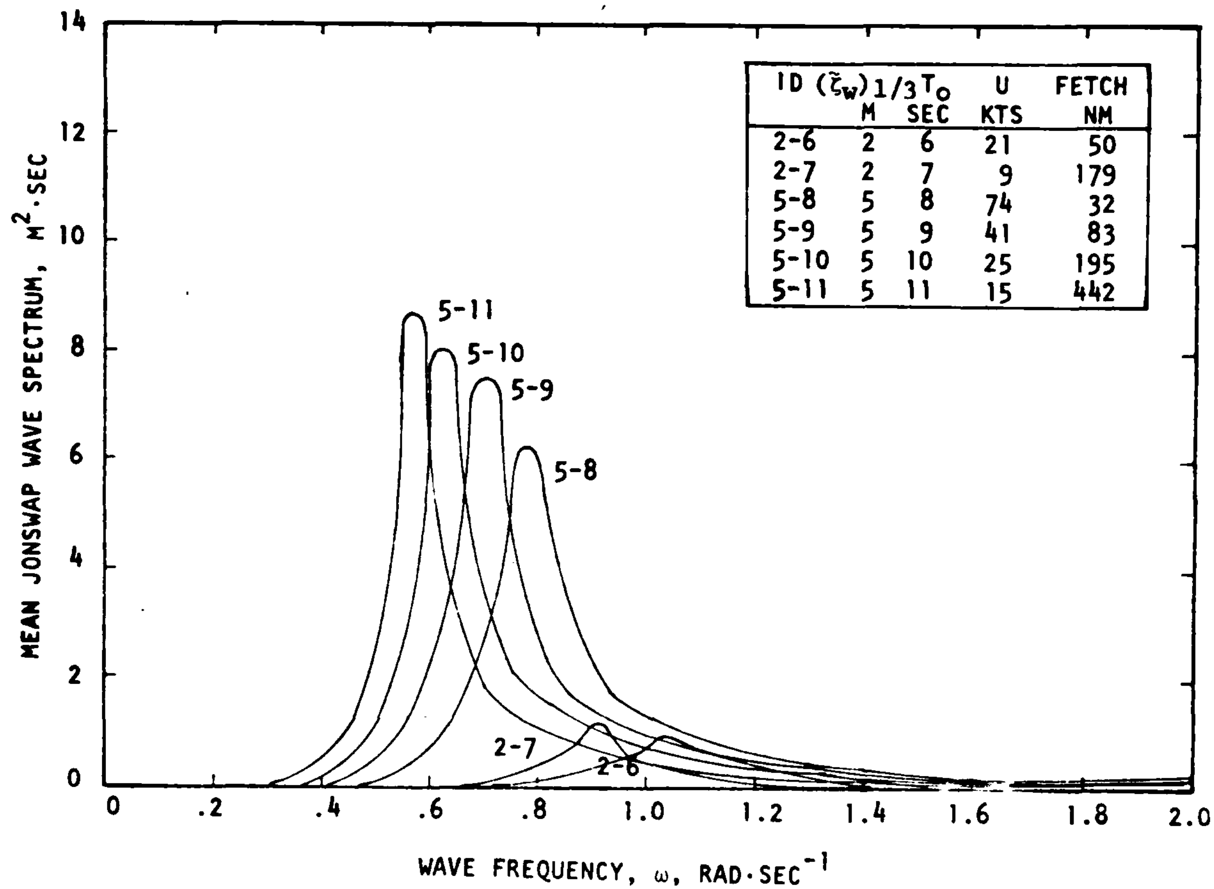

Figure 5 - Typical Modified JONSWAP Spectra For Significant Wave Heights of 2 and 5 m.

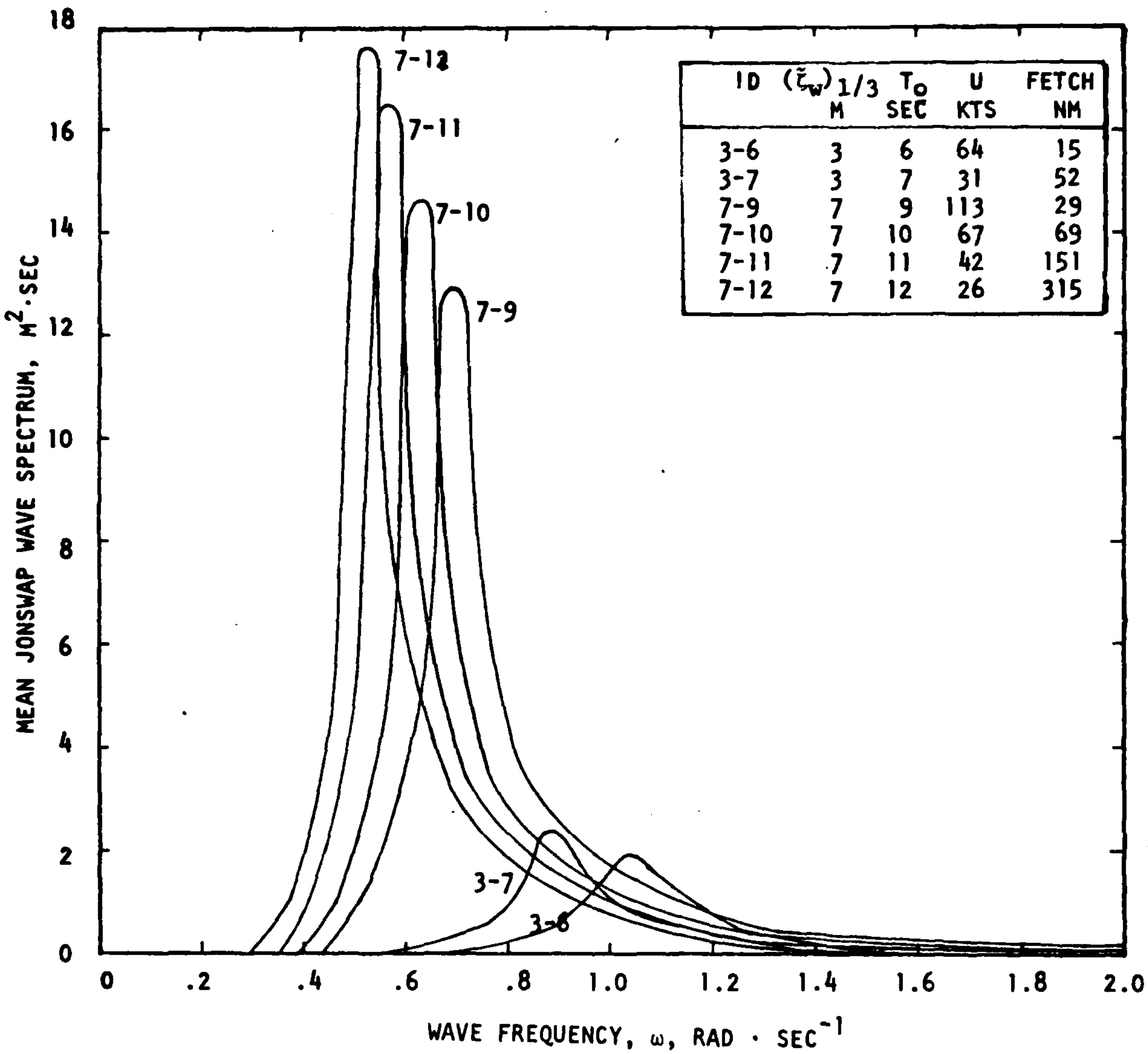

Figure 6 - Typical Modified JONSWAP Spectra For Significant Wave Heights of 3 and 7 m.

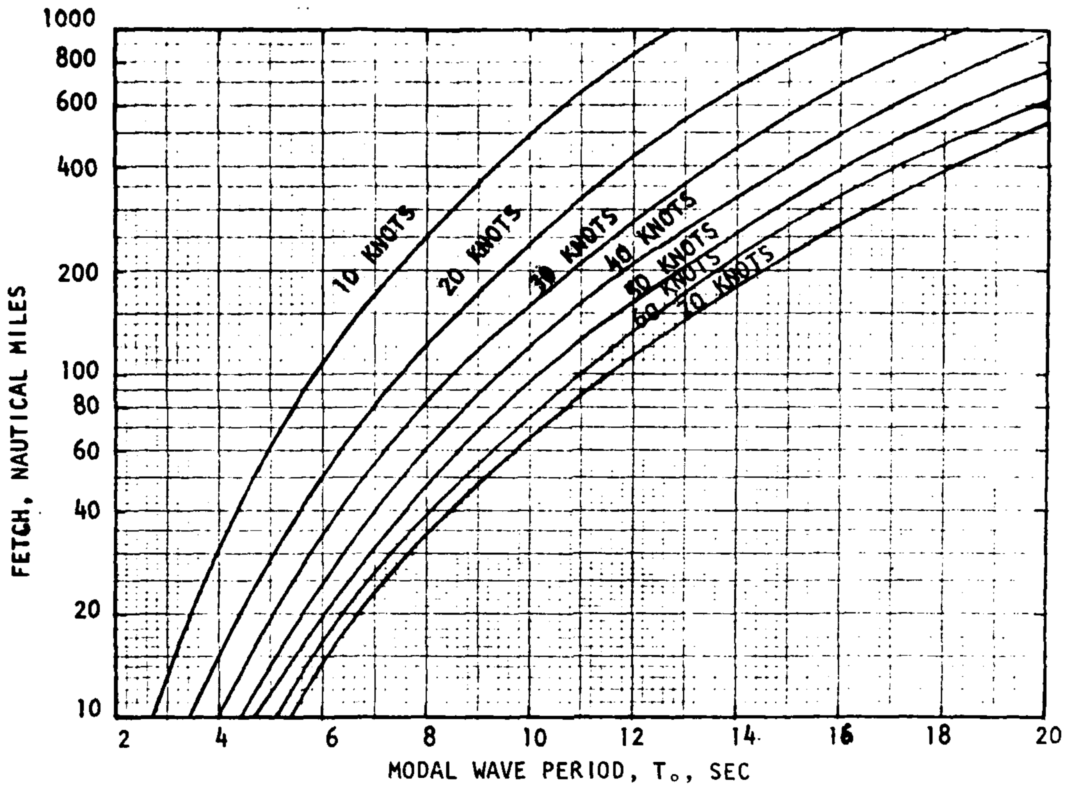

Figure 7 - Modified JONSWAP Spectral Relationships Between Modal Wave Period, Fetch, and Wind Speed

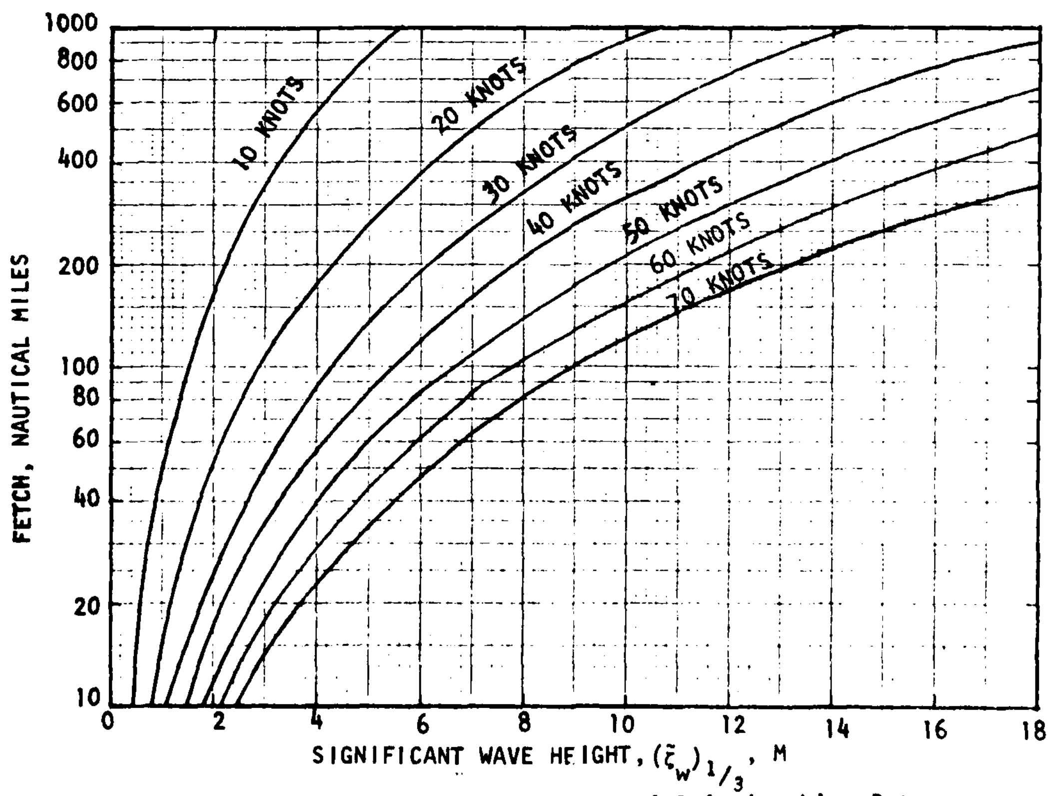

Figure 8 - Modified JONSWAP Spectral Relationships Between Significant Wave Height, Fetch, and Wind Speed

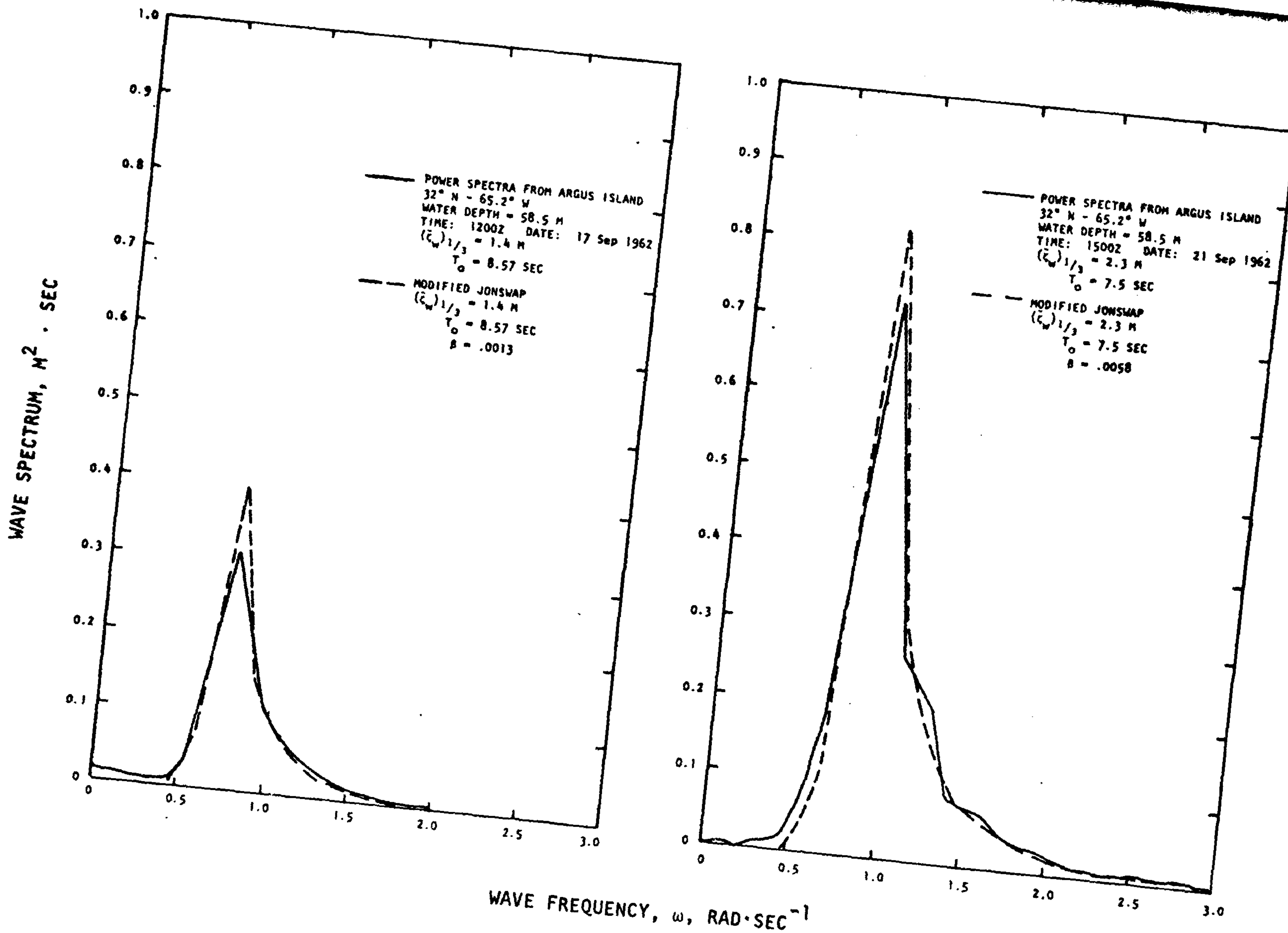

Figure 9 - Comparisons Between Modified JONSWAP Spectral and Measured Spectra.

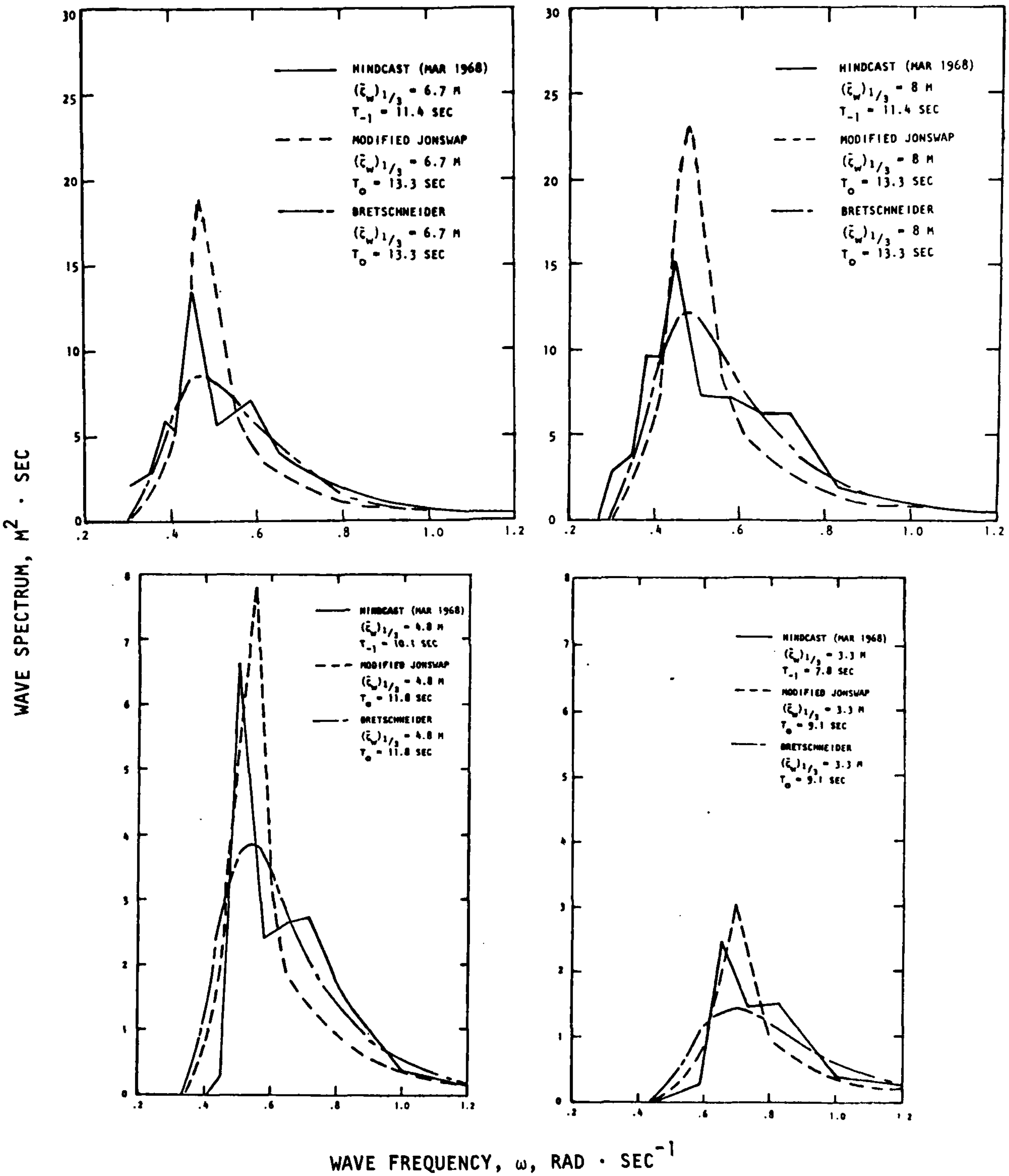

Figure 10 - Comparisons Between Modified JONSWAP, Bretschneider, and Hindcast Wave Spectra.

TABLE 1 - Significant Wave Heights for Varying Valves of γ.

	$\gamma = 1$	$\gamma = 3$	$\gamma = 3.3$	$\gamma = 5$	$\gamma = 7$
SIGNIFICANT WAVE HEIGHT, $(\tilde{\zeta}_w)_{1/3}$, M	1.6	2	2	2.2	2.4
	3.2	3.9	4	4.4	4.8
	4.9	5.9	6	6.7	7.3
	6.5	7.8	8	8.9	9.7
	8.1	9.8	10	11.1	12.1
	9.7	11.8	12	13.3	14.5
	11.3	13.7	14	15.5	16.9
	13.0	15.7	16	17.7	19.4
	14.6	17.7	18	20.0	21.8

APPENDIX
DESCRIPTION OF COMPUTER PROGRAM JON1

It has been shown in the preceding text that there is a noticeable discrepancy between the theoretical and actual significant wave heights for fetches above 40 nautical miles when the JONSWAP spectrum is applied. Therefore, a new parameter, β, is used to replace the α parameter in equation (20), eg,

$$\beta = \frac{16.942\ (\tilde{\zeta}_w)_{1/3}^{\ 1.375}}{g^{1.375}\ T_o^{\ 2.75}} \tag{24}$$

where $(\tilde{\zeta}_w)_{1/3}$ is the theoretical significant wave height in meters.

A listing of program JON1 is presented in Table 2. The purpose of the program is to calculate β, modal wave period, and actual significant wave height under the spectral area. Results are plotted on Figures 3 and 4, with β against the actual significant wave height, $(\tilde{\zeta}_w)_{1/3}$, and the modal period, T_o. For example, if the significant wave height is 4.08 m, and the modal period is 8 sec, then, by reading across the intersection at 4.08 m and 8 sec, β is seen to be about 0.0135. Substituting β value into equation (23) and the modified JONSWAP spectral can be generated by varying the values of ω. A typical output from program JON1 is presented in Table 3.

TABLE 2 - COMPUTER PROGRAM JON1

```
CHWE,CM55000,T150,P4.
CHARGE,CHWE,LCLCU15126.
FTN(I,A,OPT=1,R=3)
SETCORE(INDEF,ADDR)
LGO.
000000000000000000000
       PROGRAM JON1 (INPUT=512,OUTPUT=512,TAPE5=INPUT,TAPE6=OUTPUT)
       DIMENSION S(100),W(55)
       DATA N,PI/65,3.14159265/
       DATA W/.05,.10,.15,.20,.25,.30,.35,.40,.45,.50,.55,.60,.65,
     2 .70,.75,.80,.85,.90,.95,1.00,1.05,1.10,1.15,1.20,1.25,1.30,
     2 1.35,1.40,1.45,1.50,1.55,1.60,1.65,1.70,1.75,1.80,1.85,
     2 1.90,1.95,2.00,2.05,2.10,2.15,2.20,2.25,2.30,2.35,2.40,2.45,2.50,
     2 2.55,2.60,2.65,2.70,2.75,2.80,2.85,2.90,2.95,3.00,3.05,3.10,
     2 3.15,3.20,3.25/
       READ (5,100) NCASES
       DO 200 I=1,NCASES
       READ (5,101) FETCH,U
       CALL JONSWP1 (N,FETCH,U,SWHM,T0,W,S)
       SWHFT = SWHM*3.28
C-----BETA
      CONA=15.942*SWHM**1.375
      CONB=(9.8087**1.375)*10**2.75
      BETA=CONA/CONB
       WRITE (6,102) FETCH,U,SWHM,SWHFT,T0,BETA
       DO 180 J=1,N
       F = W(J)/(2.*PI)
       T=1./F
       SFT=S(J)*3.28*3.28
  180  WRITE (6,103) F,T,W(J),S(J),SFT
       CALL ALGRNG (N,W,S,AREA)
       RMS=SQRT(AREA)
       RMSFT=RMS*3.28
       WRITE (6,104) RMS,RMSFT
       SIGM=4.*RMS
       SIGFT=4.*RMSFT
       WRITE(6,105) SIGM,SIGFT
  200  CONTINUE
       STOP
  100  FORMAT (I5)
  101  FORMAT (8F10.5)
  102  FORMAT (1H1,* JONSWAP SPECTRUM*/* FETCH =*,F5.0,
     2 * NM, WIND SPEED =*F5.0,*KTS, SIG. WAVE HT. =*F5.2* M =*
     2 F5.2* FT MODAL WAVE PER. =*F5.2 *SECONDS    BETA=*F10.6///
     2 *X *F* 9X *T* 9X *W* 8X *S,M* 7X *S,FT*/)
  103  FORMAT (3F10.3,2F10.5)
  104  FORMAT (* INTEGRATED RMS =*F5.2 * M =*F5.2* FT*)
  105  FORMAT (* SIG. WAVE HT. =*F5.2 * M =*F5.2 * FT*)
       END
*DECK ALGR
*DECK JONS
C
C------SUBROUTINE TO COMPUTE JONSWAP SPECTRUM FROM WIND SPEED AND FETCH.
C------CALCULATION IS DONE FOR FREQUENCY F AND IN METRIC UNITS INITIALLY.
C------TO GET A PIERSON MOSKOWITZ SPECTRUM, LET ALPHA=.0081 AND
C------GAMMA=1.0.
C
      SUBROUTINE JONSWP1 (N,FETCH,U,SIGWH,T0,W,S)
       REAL NOFETCH,NOFF
       DIMENSION S(  0),W(   N)
       DATA PI,G,ERR/3.14159265,9.806,.00001/
       DATA GAMMA,SIGA,SIGB/3.3,.07,.09/
       U0=U*1.689/3.28
       FETCH0=FETCH*1852.
```

TABLE 2 - COMPUTER PROGRAM JONl (Continued)

```
      NDFETCH = G*FETCH/UU/UU
      NDFM = 3.5/(NDFETCH)**.33
      FM = NDFM*G/UU
      T0=1./FM
      SIGMA = 4.* SQRT(1.6*NDFETCH*UU*UU*UU*UU/G/G/10000000.)
      ALPHA = .076/(NDFETCH)**.22
C
C------FOR A PIERSON-MOSKOWITZ SPECTRUM, SET ALPHA=.0081 AFTER THIS
C------COMMENT CARD.
C
      CON1=ALPHA*G*G/(2.*PI)**4
      DO 100 I=1,N
      F=W(I)/(2.*PI)
      ARG1 = -1.25/(F/FM)**4
      IF ((F-FM).LE.EPS) ARG2=2.*SIGA*SIGA*FM*FM
      IF ((F-FM).GT.EPS) ARG2=2.*SIGB*SIGB*FM*FM
      ARG3=-(F-FM)*(F-FM)/ARG2
      IF (ARG1 .LT. -100.) S(I)=0.
      IF (ARG1 .LT. -100.) GO TO 100
      IF(ARG3.LT.-75.) GO TO 111
      ARG4 = EXP(ARG3)
      GO TO 112
  111 ARG4=0.
C
C------FOR A PIERSON-MOSKOWITZ SPECTRUM, SET GAMMA=1.0 AFTER THIS
C------COMMENT CARD.
C
  112 S(I) = CON1/F**5*EXP(ARG1)*GAMMA**ARG4
C
C------CONVERT SPECTRUM TO M**2-SEC (FROM M**2/HZ).
C
      S(I) = S(I) /(2.*PI)
  100 CONTINUE
      RETURN
      END
      SUBROUTINE ALGRNG ( N,W,S,AREA)
*
*FORTRAN ROUTINE TO PERFORM A LAGRANGIAN INTEGRATION.
*
      DIMENSION W(N),S(N)
      MN=N-2
      AREA=0.
      DO 20 M=1,MN,2
      A=W(M+2)-W(M)
      B=W(M+2)-W(M+1)
      C=W(M+1)-W(M)
10      AREA=AREA+A*A/6.*(S(M)*(3.*C-A)/(A*C)+S(M+1)*A/(B*C)+
     * S(M+2)*(2.*A-3.*C)/(A*B))
20     CONTINUE
      RETURN
      END
0000000000000000000000
    1
    50.    40.
0000000000000000000000
```

TABLE 3 - OUTPUT FROM PROGRAM JONI

JONSWAP SPECTRUM
FETCH = 60. NMI WIND SPEED = 40.KTS. SIG. WAVE HT. = 3.51 M =11.51 FT
MODAL WAVE PER. = 8.00SECONDS BETA= .013510 **THEORETICAL**

F	T	•	S.M	S.FT
.008	125.664	.050	0.00000	0.00000
.016	62.832	.100	0.00000	0.00000
.024	41.888	.150	0.00000	0.00000
.032	31.416	.200	0.00000	0.00000
.040	25.133	.250	0.00000	0.00000
.048	20.944	.300	.00000	.00000
.056	17.952	.350	.00000	.00000
.064	15.708	.400	.00000	.00001
.072	13.963	.450	.00067	.00716
.080	12.566	.500	.02100	.22595
.088	11.424	.550	.14467	1.55645
.095	10.472	.600	.43157	4.64299
.103	9.666	.650	.83267	8.95616
.111	8.976	.700	1.53927	16.56025
.119	8.378	.750	3.24423	34.90276
.127	7.854	.800	4.00132	43.04782
.135	7.392	.850	2.57751	27.73101
.143	6.981	.900	1.46003	15.77214
.151	6.614	.950	1.01411	10.91015
.159	6.283	1.000	.51822	6.60270
.167	5.984	1.050	.69004	7.42378
.175	5.712	1.100	.58373	6.28003
.183	5.464	1.150	.49271	5.30075
.191	5.236	1.200	.41554	4.47055
.199	5.027	1.250	.35070	3.77300
.207	4.833	1.300	.29650	3.18988
.215	4.654	1.350	.25127	2.70353
.223	4.488	1.400	.21360	2.29604
.231	4.333	1.450	.18213	1.95967
.239	4.189	1.500	.15540	1.67678
.247	4.054	1.550	.13352	1.43972
.255	3.927	1.600	.11530	1.24049
.263	3.808	1.650	.09969	1.07254
.271	3.696	1.700	.08649	.93051
.279	3.590	1.750	.07529	.80998
.286	3.491	1.800	.06575	.70737
.294	3.396	1.850	.05766	.61971
.302	3.307	1.900	.05062	.54457
.310	3.222	1.950	.04461	.47997
.318	3.142	2.000	.03943	.42423
.326	3.065	2.050	.03485	.37501
.334	2.992	2.100	.03100	.33415
.342	2.922	2.150	.02767	.29771
.350	2.856	2.200	.02472	.26590
.358	2.793	2.250	.02213	.23806
.366	2.732	2.300	.01980	.21362
.374	2.674	2.350	.01785	.19211
.382	2.618	2.400	.01609	.17313
.390	2.565	2.450	.01453	.15635
.398	2.513	2.500	.01315	.14147
.406	2.464	2.550	.01192	.12825
.414	2.417	2.600	.01083	.11648
.422	2.371	2.650	.00985	.10598
.430	2.327	2.700	.00896	.09659
.438	2.285	2.750	.00820	.08818
.446	2.244	2.800	.00749	.08063
.454	2.205	2.850	.00686	.07384
.462	2.167	2.900	.00629	.06772
.470	2.130	2.950	.00578	.06220
.477	2.094	3.000	.00532	.05721
.485	2.060	3.050	.00490	.05269
.493	2.027	3.100	.00452	.04860
.501	1.995	3.150	.00417	.04487
.509	1.963	3.200	.00386	.04149
.517	1.933	3.250	.00357	.03840

INTEGRATED RMS = 1.02 M = 3.35 FT
SIG. WAVE HT. = 4.08 M =13.39 FT
(CALCULATED FROM INTEGRATED AREA OF SPECTRUM)

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